Exercise : Environmental balance of a single family house

1 Energy related impacts

1.1 Heating (heat losses, solar and internal gains, heating load, impacts of gas heating)
1.2 Lighting (sizing artificial lighting, occupancy schedule, impacts of electricity production) + other electricity consumption
1.3 Domestic hot water (sanitary equipment + impacts of gas boiler)

2 Impacts related to the treatment of domestic waste

2.1 Glass (fabrication, sorting, recycling)
2.2 Paper (fabrication, incineration)
2.3 Other waste (incineration, possible heat recovery)

3 Other impacts

3.1 Impacts related to water consumption
cold and hot water consumption, impacts of production/distribution of drinking water, waste water treatment
3.2 Impacts related to construction materials
Fabrication, on site implementation (5% de surplus), waste treatment (inert waste or incineration); materials accounted for : concrete, concrete blocks, glass wool, polystyrene, gypsum, timber, glass, steel, clay tiles and mortar (other components are neglected.
3.3 Impacts generated by transportation
Home-work commuting, individual car or public transport.

4 Performance improvement

Alternatives will be compared to the previous case (life cycle balance) :
- bioclimatic architecture (lower heating and lighting loads)
- solar water heater
- energy recovery on waste incineration and paper sorting / recycling
- reduced water flow rate (cold and hot)
- timber construction instead of concrete
- reduction of transport distances
- energy saving domestic appliances
- wood fuel heating

Results to be provided

Environmental indicators (GWP at least) for the impacts sources (heating, water consumption, waste, transport) for the reference case and at least one alternative.

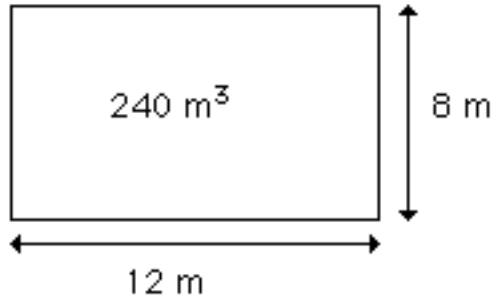
Annexes

1 Plans of the house, characteristics (site and climate, building, occupancy and use),
2 Method to evaluate heating loads,
3 Method to size artificial lighting,
4 indicators derived from life cycle inventories of materials and processes

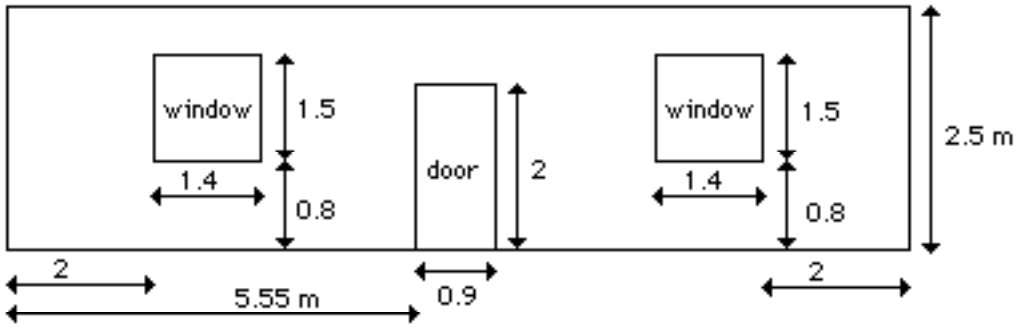
Annex 1 : description of the building and data

1 Geometry

1.1 Plan

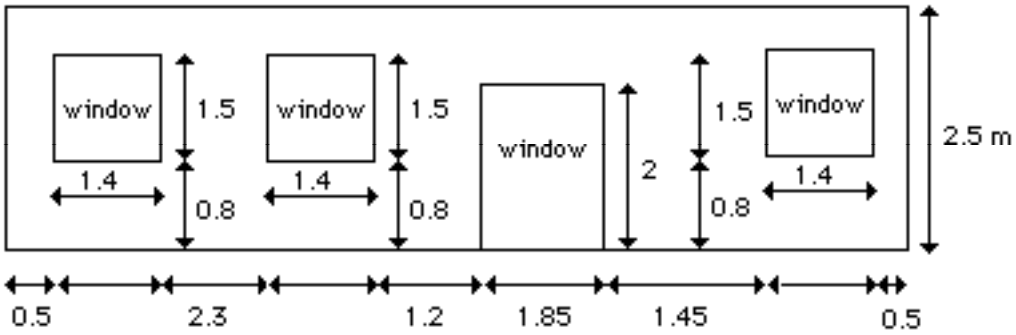


1.2 East facade



total area : 30 m^2, including windows (4.2 m^2) and door (1.8 m^2)

1.3 West facade

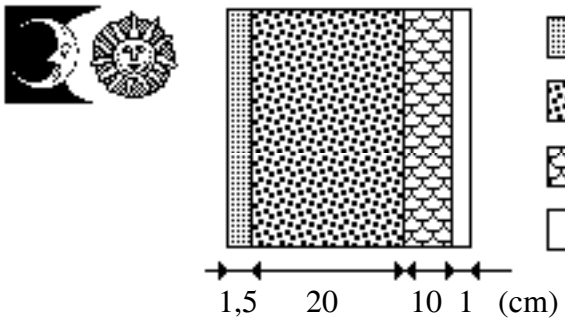


Total area : 30 m^2, including 10 m^2 windows

1.4 North and south facades, floor and roof
North and south facade area : 20 m^2
No window and door
Floor and ceiling area : 96 m^2

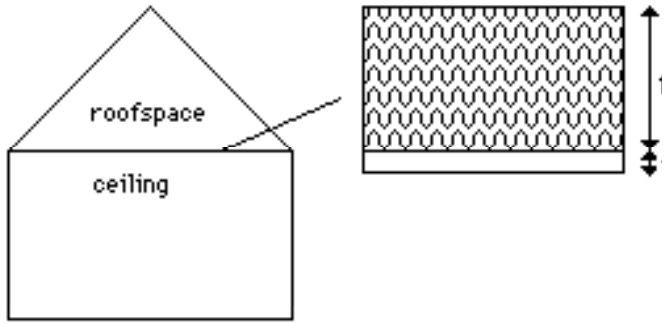
2 Construction

2.1 facades



+ internal walls : 60 m^2
with 3 cm gypsum board
+ doors : 0.2 m^3 timber

2.2 Ceiling



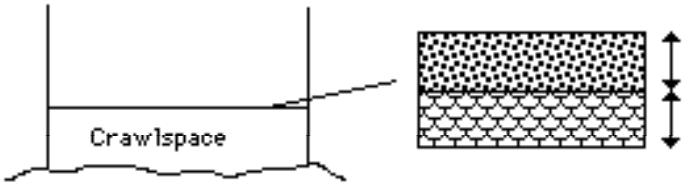
Glass wool, 20 cm

gypsum, 1 cm

+ roof : 1.5 cm clay tiles (135 m^2, density : 1900) and 0.5 m^3 timber

Ventilated roof-space (T= Text)

2.3 Floor



concrete, 20 cm
polystyrene, 8 cm

+ fondations : 8 m^3 concrete blocks and 8 m^3 concrete
+ steel (reinforcement), 0.3 m^3 density 7800 kg/m^3

Ventilated crawl space (T= T_{ext})

2.4 Properties of materials

material	κ (W/m/K)	ρ (kg/m^3)	Cp (Wh/kg/K)
mortar	1.15	2000	0.24
concrete	1.75	2400	0.26
Concdrete blocks	1.05	1300	0.18
polystyrene	0.039	25	0.34
timber	0,14	630	0,36
glass	1,05	2500	0,5
gypsum	0.35	900	0.23
Glass wool	0.041	50	0.23

2.5 Windows

double glazing (2 x 4 mm glass), wooden frame (3 cm thick) = 15% of the area
solar transmission factor of glazing : 0,72
U = 1,7 W/m^2/K, day/night average accounting for wooden shutters (2 cm thick) closed at night.

2.6 Door
U = 1 W/m^2/K (3 cm wood and 4 cm polystyrene)

2.7 Thermal bridges
0,5 W/m/K all around the floor slab.

2.8 Radiative properties of materials (inside)
walls : $\varepsilon = 0.9$ and $\alpha = 0.5$, ceiling : $\varepsilon = 0.9$ and $\alpha = 0.3$, floor : $\varepsilon = 0.9$ and $\alpha = 0.9$

2.9 Other components
Heating : 500 kg steel

3 Operation

3.1 Ventilation
Air revewal : 0.5 volume per hour (constant)

3.2 Occupancy
4 persons, lighting of 15% of the house area at 180 lux (over a working surface 0,90 m abouve the floor) during 6 hours, other electricity consumption : 2,300 kWh / year.
Occupancy 300 days per year (to be used for lighting, water consumption, domestic waste generation).

3.3 Heating
Average internal temperature 19°C, constant
Gas heating

3.4 Water consumption
Cold water : 100 l/day/ person
Hot water : 40 l /day/ person, 50°C, 10°C cold water, gas water heating.

3.5 Waste
Generation of 1,2 kg domestic waste per person and per day, including 12% glass (50% sorted) and 30% paper, not sorted
Construction waste correspond to 5% of the useful quantities, renovation and replacement of components will be neglected, demolition waste is considered as inert (landfilled) except wood and polystyrene, incinerated.

3.6 Life span : 80 years

4 Site

Paris
No shading
Latitude : 48°46' North
Longitude : 2°01' East
Glass and paper waste are collected by the municipality
Other domestic waste is incinerated (average lower heating value : 1.45 kWh / kg)
Water network (mains) efficiency : 80%
Home-work commuting: 12 km distance, one return every working day (230 per year) for 2 persons, one using individual car and the other public transport (train)

5 Alternatives

5.1 Bioclimatic design
Most glazed facade South oriented instead of West
South facing windows : 15 m^2 instead of 10
External insulation
Heat recovery on ventilation air, 80% efficiency (50% accounting for air infiltration)
Artificial lighting 5 hours a day instead of 6
The variation of material related impacts (due to higher window area) will be neglected.

5.2 Solar domestic hot water
50% reduction of yearly energy use (solar fraction)

5.3 Domestic waste treatment
50% paper sorting and 75% glass sorting
Heat recovery on waste incineration, 80% efficiency, substituting fuel
average lower heating value of incinerated waste : 1.45 kWh / kg

5.4 Water saving
Low flow rate sanitary equipment, water consumption reduced by 30%

5.5 Timber construction
- walls : mortar and concrete blocks replaced by 2 cm timber
- floor : concrete replaced by 2 cm timber

5.6 Transport
Distance of 2 km instead of 12, use of bus

5.7 Reduction of electricity consumption
Energy saving domestic appliances : 1,300 kWh/year instead of 2,300
Low consumption lighting (75% saving).

5.8 Use of wood fuel instead of gas for space and water heating

Annex 2 : heating load calculation

1 Heat losses

Superficial thermal resistances (convection + radiation heat transfer)

	Paroi en contact avec : — l'extérieur, — un passage ouvert, — un local ouvert.			Paroi en contact avec : — un autre local, chauffé ou non chauffé, — un comble, — un vide sanitaire.		
	$\frac{1}{h_i}$	$\frac{1}{h_e}$	$\frac{1}{h_i}+\frac{1}{h_e}$	$\frac{1}{h_i}$	$\frac{1}{h'_i}$	$\frac{1}{h_i}+\frac{1}{h'_i}$
Paroi verticale ou faisant avec le plan horizontal un angle supérieur à 60°	0,11	0,06	**0,17**	0,11	0,11	**0,22**
Paroi horizontale ou faisant avec le plan horizontal un angle égal ou inférieur à 60°, flux ascendant (toiture)	0,09	0,05	**0,14**	0,09	0,09	**0,18**
flux descendant (plancher bas)	0,17	0,05	**0,22**	0,17	0,17	**0,34**

Specific heat of air : 0.34 Wh/m3/K
Heating degree days in France : 58000 (North), 47000 (intermediate) , 32000 (Mediterranean)

2 Internal gains

Ai (kWh) = Floor area x 22.9 (North), 21.7 (intermediate) or 18.1 (Mediterranean)

3 Solar gains

As = (Σ A Fts Fe C1) . E
For each window :
A : window area (glazing + frame)
Fts = Fs (solar transmission factor of the glazing, see annex 1) x proportion of glazing
Fe : shading coefficient (1 if no shading)
C1 : according to orientation and slope, see table hereunder
E : solar radiation on a vertical South plane, 410 kWh/m2 (North), 440 (intermediate) or 460 (Mediterranean)

Inclinaison de la paroi sur l'horizontale, en degrés	Orientation de la paroi				
	SSE à SSO	SSE à ESE et SSO à OSO	ESE à ENE et OSO à ONO	ENE à NNE et ONO à NNO	NNE à NNO
De 85 à 90	1	0,85	0,55	0,30	0,20
De 70 à 84	1,15	0,95	0,60	0,35	0,20
De 55 à 69	1,20	1,05	0,65	0,35	0,25
De 40 à 54	1,20	1,05	0,75	0,40	0,30
De 25 à 39	1,15	1,00	0,75	0,50	0,40
De 10 à 24	1,00	0,95	0,80	0,65	0,55
De 0 à 9	0,80	0,80	0,80	0,80	0,80

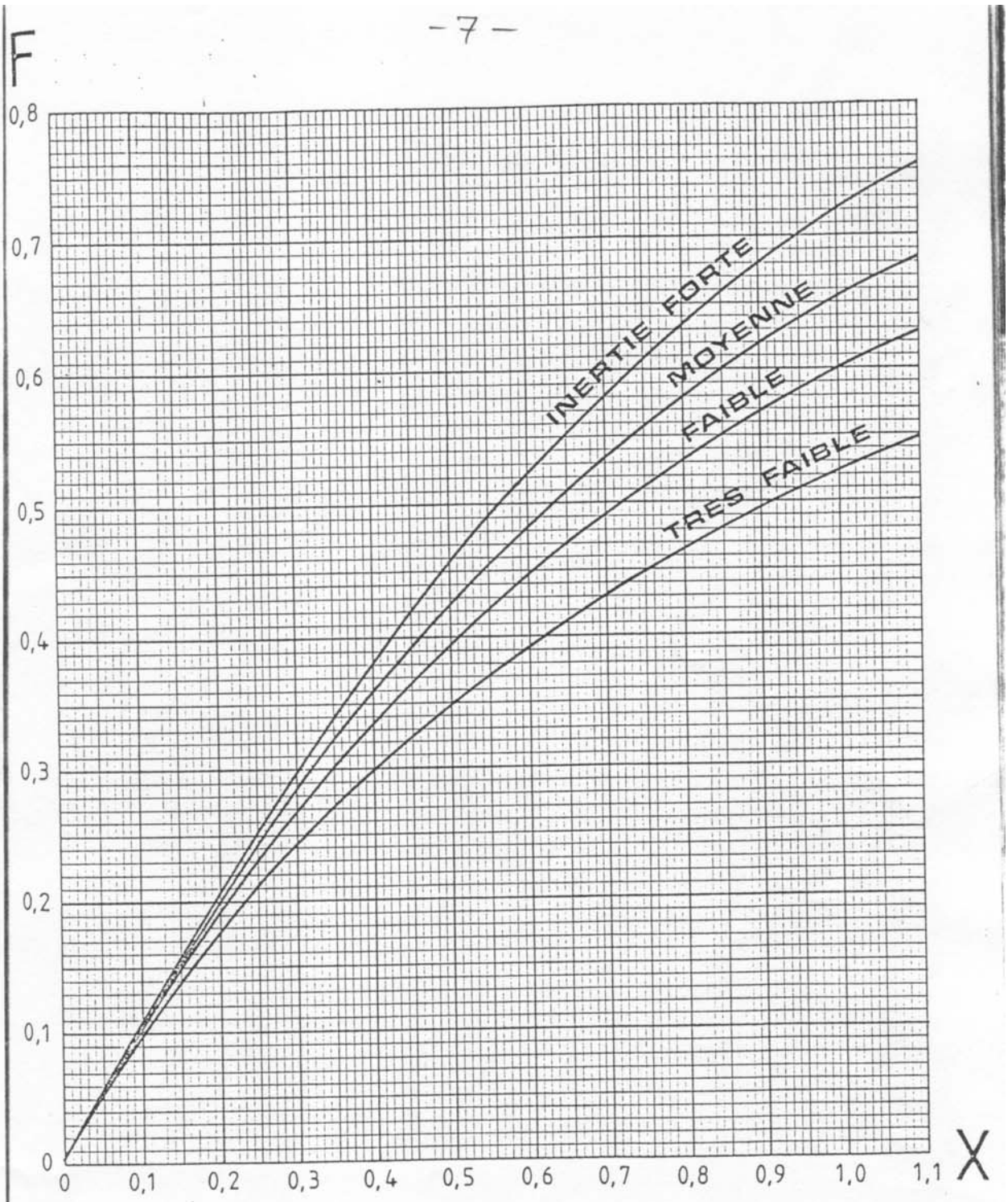
4 Heating load

X = (solar gains + internal gains) / heat losses
Thermal mass, see table hereunder

single family house :

Thermal mass level	
High	Heavy walls and floor
Average	Heavy floor
Low	Heavy walls
Very low	No heavy floor and wall

F is provided on the following graph.



Les formules correspondant à ces courbes sont :

inertie forte : $F = \frac{X - X^{3.6}}{1 - X^{3.6}}$

inertie faible : $F = \frac{X - X^{2.5}}{1 - X^{2.5}}$

inertie moyenne : $F = \frac{X - X^{2.9}}{1 - X^{2.9}}$

inertie très faible : $F = \frac{X - X^{2.1}}{1 - X^{2.1}}$

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Heating load = Heat losses x (1 – F)
Or Heating load = Heat losses – τ . Gains
Utilisability factor of gains, τ, is F / X

Annex 3 : artificial lighting
(standard NF-C71-121)

1 Data on lamps and reflectors

Lighting efficiency of an incandescent bulb : η = 13 lumen / W
Power of one bulb : 100 W
Efficiency of the reflector : ηsi = 0.6 downwards and ηss = 0.1 upwards
Class of the reflector : C
Uniform distribution of the lamps in a grid, distance between 2 lamps : m=3 meters in length and n = 2 meters in width, distance between one lamp and a wall (in both directions) : p=q=0 meter.
The distance between lamps and ceiling is neglected (h' = 0), the working plan is 0,90 meter above the floor (h = 1,6).

2 Calculation of illuminance

- notations :
N : number of lamps
P : electric power of a lamp
a : room width
b : room length
K = a.b / (h . (a+b))
Km = 2 m.n / (h. (m+n))
Kp = (a.p + b.q) / (h . (m+n))
j = h' / (h + h')

K, Km and Kp allow F''u to be derived from table 1 (next page).
j and K allow R4, S4inf (use class C) and S4sup (class T) to be derived from table 2 ($\rho 1$ is the refexivity of the ceiling, $\rho 3$ of the walls and $\rho 4$ of the floor)
The illuminance provided downwards by the reflector (Einf) and the illuminance upwards refected to the working plan (Esup) can then be calculated :
Einf = N P η ηsi (R4 . F''u + S4inf) / (1000 a b)
Esup = N P η ηss S4 sup / (1000 a b)

The total illuminance on the working plan can be derived : E (lux) = Einf + E sup

Table 1 : Flux relatif partiel sur le plan utile

Tableau IV-7
Valeurs du flux relatif partiel sur le plan utile F''_u pour les installations de référence d'indice du local $K = 2,5$

CLASSE DU LUMINAIRE	INDICE DE MAILLE k_m											
	0,5			1			1,5			2		
	Indice de proximité k_p			Indice de proximité k_p			Indice de proximité k_p			Indice de proximité k_p		
	0	0,25	0,5	0	0,5	1	0	0,75	1,5	0	1	2
A	782	877	939	683	909	975	594	944	980	497	972	977
B	753	839	900	665	865	944	584	895	959	494	930	970
C	709	786	846	634	805	899	563	832	923	478	874	945
D	679	748	805	612	763	857	548	787	885	471	827	918
E	649	710	763	590	722	816	534	741	848	465	780	890
F	678	740	801	621	748	873	564	768	914	487	823	966
G	588	642	689	537	653	735	489	668	764	429	701	805
H	540	589	630	493	598	672	450	613	698	396	641	734
I	586	635	682	542	640	737	499	652	776	442	692	832
J	460	498	533	425	503	571	392	515	598	347	541	633
T	0	0	0	0	0	0	0	0	0	0	0	0

Tableau IV-8
Valeurs du flux relatif partiel sur le plan utile F''_u pour les installations de référence d'indice du local $K = 3$

CLASSE DU LUMINAIRE	INDICE DE MAILLE k_m											
	0,5			1			1,5			2		
	Indice de proximité k_p			Indice de proximité k_p			Indice de proximité k_p			Indice de proximité k_p		
	0	0,25	0,5	0	0,5	1	0	0,75	1,5	0	1	2
A	816	899	953	727	927	983	637	963	987	561	982	985
B	790	866	920	710	889	957	629	920	973	558	943	980
C	747	815	868	678	831	913	606	859	939	539	887	952
D	721	784	835	659	797	881	595	821	913	534	848	933
E	696	753	803	641	764	849	585	783	887	529	809	913
F	721	779	835	668	786	894	611	806	945	550	843	975
G	638	688	731	589	694	773	539	713	808	491	734	834
H	588	634	673	544	642	710	499	656	742	455	676	766
I	638	685	731	596	690	780	552	702	827	505	728	862
J	507	543	577	492	548	611	437	558	642	402	577	666
T	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 : valeurs des coefficients R et S

RÉFÉRENCE DU TABLEAU	RAPPORT DE SUSPENSION	INDICE DU LOCAL	FACTEURS DE RÉFLEXION	CES COEFFICIENTS PERMETTENT LE CALCUL DES ECLAIREMENTS MOYENS SUR :								
				Le plafond et la frise $E_1 = \frac{NF}{1000\ ab}(R_1F^*+S_1)$			Les murs $E_3 = \frac{NF}{1000\ ab}(R_3F^*+S_3)$			Le plan utile $E_4 = \frac{NF}{1000\ ab}(R_4F^*+S_4)$		
					S_1			S_3			S_4	
	j	K	ρ_1 ρ_3 ρ_4 x 10	R_1	Classe		R_3	Classe		R_4	Classe	
					A à J	T		A à J	T		A à J	T
7	0	2,5	8 7 3	- 0,204	523	1306	- 1,481	1770	598	0,566	673	851
			8 7 1	- 0,308	400	1150	- 1,575	1659	457	0,488	580	734
			7 7 3	- 0,196	504	1258	- 1,467	1732	504	0,587	619	717
			7 7 1	- 0,302	393	1129	- 1,558	1636	392	0,516	544	630
			7 5 3	- 0,044	324	1205	- 1,321	1560	454	0,774	398	653
			7 5 1	- 0,174	257	1096	- 1,432	1503	360	0,694	358	586
			7 3 1	- 0,065	143	1069	- 1,324	1390	333	0,846	198	547
			7 1 1	0,029	44	1045	- 1,232	1293	310	0,976	62	515
			5 5 1	- 0,169	251	1067	- 1,414	1478	251	0,723	315	407
			5 3 1	- 0,063	140	1048	- 1,318	1378	234	0,856	176	383
			5 1 1	0,029	44	1032	- 1,235	1290	219	0,972	55	363
			3 3 1	- 0,062	137	1028	- 1,313	1364	137	0,865	156	226
			3 1 1	0,028	43	1019	- 1,237	1286	130	0,968	49	215
8	0	3	8 7 3	- 0,204	534	1308	- 1,739	2037	610	0,555	694	881
			8 7 1	- 0,308	402	1141	- 1,834	1918	460	0,476	595	755
			7 7 3	- 0,196	514	1259	- 1,724	1998	514	0,577	638	742
			7 7 1	- 0,303	396	1122	- 1,816	1836	396	0,505	558	649
			7 5 3	- 0,042	335	1213	- 1,575	1825	470	0,768	416	685
			7 5 1	- 0,176	263	1094	- 1,689	1763	368	0,684	370	610
			7 3 1	- 0,065	148	1070	- 1,578	1648	344	0,840	208	576
			7 1 1	0,032	46	1049	- 1,481	1546	323	0,977	65	546
			5 5 1	- 0,171	256	1065	- 1,671	1736	256	0,714	325	424
			5 3 1	- 0,064	145	1049	- 1,572	1633	241	0,851	184	404
			5 1 1	0,032	45	1034	- 1,484	1542	227	0,972	58	385
			3 3 1	- 0,063	142	1029	- 1,566	1620	142	0,861	161	237
			3 1 1	0,031	45	1020	- 1,487	1538	135	0,967	51	228
9	0	4	8 7 3	- 0,203	548	1310	- 2,252	2561	626	0,541	723	920
			8 7 1	- 0,309	406	1130	- 2,347	2435	465	0,460	615	783
			7 7 3	- 0,195	527	1261	- 2,237	2521	528	0,563	662	775
			7 7 1	- 0,304	400	1112	- 2,329	2411	400	0,489	576	674
			7 5 3	- 0,039	351	1224	- 2,082	2346	491	0,760	441	729
			7 5 1	- 0,178	269	1090	- 2,200	2278	378	0,670	389	643
			7 3 1	- 0,066	153	1071	- 2,084	2158	358	0,832	221	615
			7 1 1	0,036	49	1054	- 1,980	2050	340	0,978	70	590
			5 5 1	- 0,174	263	1063	- 2,181	2249	263	0,702	340	447
			5 3 1	- 0,064	151	1050	- 2,078	2142	251	0,844	194	430
			5 1 1	0,035	48	1038	- 1,983	2045	239	0,972	62	415
			3 3 1	- 0,063	147	1029	- 2,071	2127	147	0,855	169	253
			3 1 1	0,035	47	1022	- 1,987	2040	141	0,966	54	245

Annex 4 : indicators derived from life cycle inventories of materials and processes

		Heating, kWh load				
	unit	kWh gas	kWh fuel	kWh wood	KWh elec heat	kWh elec base
GWP	kg CO_2	0,28	0,37	0,02447	4.86E-01	8.67E-02
Primary energy	kWh	1,56	1,646	2,624	5.20E+00	6.93E+00
acidification	kg SO_2	0,00037	0,0008515	0,0008005	3.31E-03	5.99E-04
smog	kg C_2H_4	0,00011	0,0004039	0,0002159	3.19E-04	6.02E-05
eutrophication	kg PO_4	0,0000448	0,0000548	0,0000944	2.22E-04	4.06E-05
water	m^3	0,0003744	0,001148	0,0003132	9.99E-02	2.46E-02
Rad. waste	dm^3	1,885E-06	2,324E-06	1,795E-06	3.60E-05	7.52E-05
Other waste	kg eq. inert	0,025	0,02426	0,01657	2.18E-02	1.16E-02

	kg new paper	kg rec. paper	kg new glass	kg rec. glass	kg waste incinerated	m3 drinking water	Waste water treatment per person / year
GWP	0.43	0.11	1.27	1.01	0.77	0,0087	24,65
Primary energy	10.76	1.22	4.97	3.09	0,31	3,38	216,6
acidification	0,01446	0,007666	0,004456	0,00381	0,00032	0,000669	0,1547
smog	0,002575	0,001679	0,0006518	0,000445	0,000148	8,15E-06	0,04509
eutrophication	0,001224	0,0002985	0,0002452	0,000206	0,000021	3,94E-05	3,007
water	0,034	0,017	0,079	0,0172	0,097	1,01	1,071
Rad. waste	0,00005866	0,00002933	0,00000976	0,00000488	8.7E-10	3,56E-05	1,76E-03
Other waste	0,1502	0,0706	0,393	0,150	0,18	0,0069	3,977

	kg concrete	kg mortar	kg polystyrene	kg gypsum	kg glass wool	kg timber	kg steel
GWP	0,133	0,18	3	0,136	0,98	-1.72	2,09
Primary energy	0,28	0,39	29,3	0,59	5,82	7,63	12
acidification	0,00036	0	0,008	0,0013	0,0078	0,000337	0,0052
smog	3,40E-05	0,0005	0,007	0,00053	0,00091	0,000076	7,00E-04
eutrophication	4,60E-05	0,0000687	0,0011	0,000085	0,00089	0,000055	0,00056
water	0,00069	0,00015	0,035	0,002	0,029	0,0028	0,025
Rad. waste	8,50E-06	0,000014	0,0045	0,00000067	0,0000106	0,00003	3,10E-05
Other waste	0,0076	0,05	0,42	0,0013	0,058	0,123	0,74

	m2 painting	kg concrete blocks	kg clay tile	pkm car	pkm bus	pkm train	Average inhabitant (F)
GWP	0,255	0,125	0.247	0,187	0,049	0,006	8680
Primary energy	1,92	0,26	0.84	0,85	0,22	0,04	48760
acidification	0,0017	0,00052	0.00094	0,0012	0,0004	3,90E-05	62.3
smog	0,00056	0,0004	0.000457	0,00091	0,00043	2,60E-05	19.7
eutrophication	8,20E-05	0,000064	6.79e-5	9,90E-05	5,20E-05	3,90E-06	38.1
water	0.0077	0,0007	0.00147	0,00146	0,000347	0,000143	339
Rad. waste	1,70E-05	0,0000035	0	1,10E-05	2,97E-06	3,00E-07	0.51
Other waste	0,042	0,025	0.025	0,049	0,013	0,013	10400

Source : Frischknecht R., et al. , 1996, Oekoinventare von Energiesystemen, 3. Auflage, ETH Zürich / PSI Villigen
See also www.ecoinvent.ch